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ABSTRACT

This study investigates the relationships between student beliefs about the nature of science, student attitudes, and conceptual change about the nature of forces in a traditional high school physics classroom. Students (N=28) in the study were junior-level high school honors students in an introductory physics class. The physics instruction was integrated with pre-calculus. In this naturalistic study, data sources included videotape of seven weeks of instruction; analysis of videotapes using the Secondary Teacher Analysis Matrix; field notes; pretest and posttest assessments with the Force Concept Inventory; student responses from the Views on Science-Technology-Society questionnaire, the Questionnaire for the Assessment of a Science Course, and the Constructivist Learning Survey; student interviews; and teacher interviews. This study concluded that students do not think that physics is relevant to their everyday experiences, high conceptual change students are more likely to have a logical world view, and high conceptual change students are able to develop internally consistent understanding of content. (Contains 32 references.) (DDR)

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Students' Beliefs, Attitudes, and Conceptual Change in a Traditional High School Physics Classroom

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Abstract: In this study, the relationships between student beliefs about the nature of science, student attitudes, and conceptual change about the nature of forces were investigated within a traditional high school physics classroom. Students were junior-level high school, honors students taking a first-year high school physics course, and were primarily white and middle to upper SES. Physics instruction was integrated with pre-calculus. Due to the interrelated nature of the factors to be studied and the complexity of their interactions, a naturalistic inquiry was chosen. The data sources included videotape of 7 weeks of instruction; analysis of videotapes using the Secondary Teacher Analysis Matrix (Gallagher & Parker, 1995); field notes; pretest/posttest assessment with the Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992); student responses from the Views on Science-Technology-Society questionnaire (Aikenhead & Ryan, 1992), the Questionnaire for the Assessment of a Science Course (Chiappetta, 1995), and the Constructivist Learning Survey (Taylor, Fraser, & White, 1994); student interviews; and teacher interviews. The study found that (a) students did not think that physics was relevant to everyday experiences; (b) high conceptual change students were more likely to have an angular, or logical world view (Cobern, 1993) and have views which are similar to the views of the teacher about the nature of science; and (c) high conceptual change students were able to develop an internally consistent understanding of the content; however, that content sometimes appeared to be isolated knowledge.

Conceptual change is often necessary in physics if students are to come to a full understanding of concepts. Conceptual conflicts often arise in Newtonian physics because students have developed their ideas about the physical world while living with friction and with the perception of the sum of forces acting on objects. The Newtonian view of the world requires students to imagine a frictionless world and to separate the perceived force into a sum of separate forces which are sometimes difficult to identify. In addition, students must enter into a complex system of interconnected and interdependent abstract concepts. It is no wonder that many students feel that physics has little to do with the world outside of school and makes no sense. After all, they are frequently asked to abandon their ideas about the physical world in favor of concepts that conflict with their prior everyday experiences.

Posner et. al. (1982) proposed an essentially cognitive model of how conceptual change takes place within the learner based on the history and philosophy of science advocated by Thomas Kuhn (1970) and Irme Lakatos (1994) and on the equilibration theory of cognitive change of Jean Piaget (Piaget, 1968; Piaget, 1970; Piaget & Inhelder, 1969). However, since that time, they have stated that other factors besides rational arguments are necessary for conceptual change to take place (Strike & Posner, 1992). In addition, other science educators have advocated the importance of social and affective factors that influence conceptual change (Osborne & Wittrock, 1983; Pintrich, Marx, &, 1993; Pines & West 1986; Gunstone, Gray, & Searle, 1992; Stenhouse, 1986; Dreyfus, Jungwirth, & Eliovitch, 1990; Duschl & Gitomer, 1991; Pintrich et al., 1993).

Conceptual change within a classroom is a complex process. Even though conceptual change occurs within an individual and has an essentially rational component, it also is affected by the beliefs and attitudes of the individual. In addition, conceptual change takes place within a classroom context that involves complex student-student interactions and student-teacher interactions. This study investigated the interactions of student beliefs, student attitudes, classroom environmental factors, and conceptual change in a traditional, discipline-centered high school physics classroom. It is part of a larger study (Adams, 1997) in which these interactions

were also investigated in a constructivist high school physics classroom. The results of that portion of the study are reported elsewhere (Adams & Chiappetta, 1998).

Purpose

The purpose of the study was to investigate the relationships between student beliefs about the nature of science, student attitudes, classroom environmental factors, and conceptual change about the nature of forces within a traditional high school physics classroom. The beliefs, attitudes, and learning of high and low conceptual change students were compared. The purpose of these comparisons was to identify beliefs or attitudes that may favor conceptual change within a particular context. The following research questions were posited:

- **Research Question 1:** How do student views on the nature of science relate to conceptual change within a traditional high school physics classroom?
- **Research Question 2:** How do student attitudes about the classroom environment relate to conceptual change within a traditional high school physics classroom?
- **Research Question 3:** What classroom environmental factors seem to facilitate conceptual change within a traditional high school physics classroom?

Participants and Classroom Context

The classroom was located in an urban school district that served approximately 29,000 students. The school had an enrollment of 1812. The drop out rate was 1% and the average SAT score was 1005. Low SES students comprised 8% of the school population (Houston Chronicle, 1996). The school was on block scheduling which meant that every class met for 90 minutes every other day for the entire school year.

The class participating in the study was a Physics I Honors class. There were 29 students in the class and 28 participated in the study; however, two of the students in the study did not take all of the questionnaires and tests due to absence. Of the 28 students in the study, 14 were girls, and 14 were boys. Nineteen were white; 8 were Asian; and 1 was Hispanic. All of the students in the class were juniors and were a year ahead of most of their classmates in math. This physics class was integrated with a special calculus course. The calculus course was the first year of a two year sequence in which calculus and pre-calculus were integrated. This was done primarily so that content could be presented more efficiently. Students in these special classes committed to taking the second part of the calculus course in their senior year. Therefore, this class was a highly selective and motivated group of honor students.

The physics class met second period every other day for 90 minutes; however, the calculus course also ran second period every other day. Both the math teacher and the physics teacher were present every day in each other's classes so that they could team teach and better integrate the course. The physics teacher, who will be called Mrs. Hamilton, had been a teacher for 31 years and a physics teacher for 24 years. She also taught AP Physics II, which is a calculus based course. She had a bachelor's degree in teacher education and a master's degree in education and was also the science department chair. Mrs. Hamilton was always well prepared for class and liked to make physics fun by making jokes, especially puns. The students seemed to enjoy her humor and respect her.

On days when homework problems were due, Mrs. Hamilton modeled how to work problems by first drawing a picture of the situation, writing down the known information and what they needed to find, and then choosing the correct formula. She asked questions directed at the class in general as she solved the problems. When a student responded with the correct answer, she went on. Students were expected to read the material in the text before lectures. Lectures included demonstrations. Some of the demonstrations were on video (Physics Video Classics, 1993). Students also did worksheets in class in small groups of their own choosing and did labs in assigned groups. The class was observed from September 6th through October 21st. During those seven weeks, the class engaged in four labs. The labs followed the explanation of concepts and

provided further application. During the six weeks of observed instruction, students were presented the following material: linear motion under uniform acceleration, Newton's Laws, friction, two-dimensional free-body diagrams, free fall, torque, simple harmonic motion, projectiles and circular motion. The pace was almost a chapter a week from their textbook and a week of instruction consisted of two or three 90 minute periods.

This class was designated traditional because it was discipline based and because it was rated predominately conceptual by the Secondary Teacher Analysis Matrix-Science Version (STAM) (Gallagher & Parker, 1995) which is described below.

Instrumentation and Other Data Sources

Force Concept Inventory (FCI)

Conceptual change was measured by a pretest/posttest comparison of scores on the Force Concept Inventory test (Hestenes, Wells, & Swackhamer, 1992). This test was composed of 30 multiple choice questions that were constructed so that students must choose between a Newtonian view of forces and common intuitive misconceptions about the nature of forces. Therefore, an increase in correct responses should have indicated a change in a student's concept about forces to a more Newtonian viewpoint and not merely that the student had acquired additional knowledge about forces. This test was chosen because it directly confronts the misconceptions that students find difficult to change. In addition, the concepts addressed by each item of the test and the misconceptions exhibited by incorrect answers were well documented.

Views on Science-Technology-Society (VOSTS)

The instrument Views on Science-Technology-Society (VOSTS) (Aikenhead & Ryan, 1992; Ryan & Aikenhead, 1992) was developed to measure views on the nature of science and the social context of science. It was used to determine both the students' and the teachers' beliefs about the nature of science. The VOSTS instrument is a 114 multiple-choice test that was developed empirically through a five step process. This process was employed so that the items would reflect a wide range of commonly held beliefs by students about the nature of science and the social context of science. Only the items relating to the nature of science and the social aspects involved in the scientific enterprise were used in the study because technology and society views are not of interest in this particular study. This portion of the instrument measured students' beliefs about "the meaning of science, scientific assumptions, values in science, conceptual inventions in science, scientific method, consensus making in science, and characteristics of the knowledge produced in science," (Ryan & Aikenhead, 1992, p. 559).

Questionnaire for Assessment of a Science Course (QUASC)

Student attitudes about the classroom environment were measured by the Questionnaire for Assessment of a Science Course (QUASC) (Chiappetta, 1995). This Likert scale questionnaire had questions relating to student feelings about the class, student views about the relevancy of the course material, and student perceptions about classroom activities. It also included two free response questions about what students liked about the course and what students did not like about the course. Feelings about the classroom, perceived course work relevancy, and student perceptions about activities might have affected student willingness to actively participate in instructional activities that are designed to facilitate conceptual change.

Secondary Teacher Analysis Matrix-Science Version (STAM)

Every lesson during the instructional time devoted to force concepts was videotaped. The videotaping lasted seven weeks. The tapes were used first of all to analyze the classroom context including content, teacher's actions and assessments, students' actions, resources, and environment. This analysis was facilitated by the Secondary Teacher Analysis Matrix-Science Version (STAM). The matrix categorized the above mentioned classroom characteristics into six different teacher styles: didactic, transitional, conceptual, early constructivist, experienced constructivist, and constructivist inquiry. The matrix helped focus on and document specific

classroom environmental factors within each classroom environment. This instrument has a constructivist viewpoint, and therefore facilitated the analysis of the video tape within the framework chosen for the study.

Constructivist Learning Environment Survey (CLES)

In addition to videotape analysis, student perception of the constructivist nature of the classroom environment was measured by the Constructivist Learning Environment Survey (CLES) (Taylor, Fraser, & White, 1994). This survey employed Likert scale items in six subscales: Personal Relevance, Scientific Uncertainty, Critical Voice, Shared Control, Student Negotiation, and Attitude. This instrument measured the perceived classroom environment in terms of a constructivist viewpoint and provided an interesting comparison to the constructivist environment measure provided by the STAM video tape analysis. The CLES also had some overlap with the QUASC. They both measured relevance of the curriculum and student attitudes about the classroom environment.

Methodology

Due to the complexity of interactions within the study, a naturalistic inquiry research design (Lincoln & Guba, 1985) was chosen. The data collection and analysis were done in phases. Some of the preliminary analysis was used to make decisions about the design as the study progressed. Data sources included both individual data and contextual data. The data sources had many overlapping areas of measurement in order to facilitate the triangulation of data. Assertions were developed for each research question, and each assertion had at least three data sources to support it. Conclusions were then drawn from assertions and data sources for each classroom. The appendix summarizes the assertions and their associated evidence and data sources.

Phase 1

Ninety-seven percent of the students in the class participated. Consent and assent forms were returned quickly enough to videotape all but one of the days in the force unit. The Force Concept Inventory was given the first week of school. The teachers were interested in using it as a pretest/posttest whether or not students participated in the study.

Phase 2

While waiting for consent forms to be returned, both sections were observed and field notes were taken. This was done in part to give students and teachers time to get accustomed to the presence of the researcher in the classroom. In addition, it was also an opportunity to determine the best placement of the camera during lecture, demonstrations, labs, and small group work.

Phase 3

Videotaping of the targeted instruction began. Field notes were also recorded. Quotes from students and teachers that seemed important were recorded and a running time was kept to facilitate locating quotes and activities on the videotapes later. Analysis of the videotapes using the STAM was done on a regular basis throughout the videotaping. The primary researcher received instruction on how to use the matrix from Kristen Ham at Texas A & M University, who had used the matrix in her research. The peer debriefer also viewed some of the videotapes and used the STAM to independently determine teaching style. Results were then compared to those of the primary researcher and found to be very similar. Videotaping began the 4th week of school and continued through the 10th week of school. During labs or group work, a particular group was selected for videotaping.

Phase 4

After the targeted instruction was finished, students were given the following pencil and paper tests: the Force Concept Inventory (FCI) posttest, Views on Science-Technology-Society (VOSTS) survey, Questionnaire for Assessment of a Science Course survey (QUASC), and the

Constructivist Learning Environment Survey (CLES). The student wrote their name on their tests. Results were tabulated for each student and put into a database.

Pretest-posttest scores on the FCI were analyzed using a two tailed, paired t-test. The null hypothesis for this analysis was: there is no statistically significant difference between the force concepts of students before instruction and the force concepts of students after instruction. The ninety-five percent confidence level ($p < .05$) was used to determine statistical significance. The class showed a statistically significant difference between pretest and posttest scores.

Delta scores, which were calculated by subtracting the pretest score from the posttest score, were calculated for each student in the study and were used as the criteria for selecting students for Phase 5 data collection. Two groups of students were selected for interviews. One group consisted of students with high delta scores, indicating high conceptual change; the other group consisted of students with low delta scores, indicating low conceptual change. The preliminary data analysis of all data sources guided the selection of the questions for the Phase 5 interviews of students and teachers. The preliminary analysis was also discussed with the peer debriefer.

The teacher interviews centered around their teaching philosophy and goals for the class. Preliminary results were presented to the teachers for comment.

Before each interview specific areas for questioning based on their responses were determined for each student. The following issues were discussed during the interviews:

- What aspects of the class were the most helpful in coming to understand forces? In particular, high conceptual change students were asked about specific items that they answered correctly on the posttest, but missed on the pretest.
- What might have been done differently in the class to help you learn?
- The CLES responses indicated more time for student negotiation of meaning than classroom observations warranted. Therefore, students were asked what they were counting as times when they could discuss content with other students.
- Relevancy of content seemed to be an issue in the study. Therefore, students were asked, (a) Do you play a sport? Do you ever think about physics in connection to that sport? (b) Do you drive? Do ever think about physics in connection to driving? (c) When working a problem in class that concerns driving or a sport, do you think about your driving experiences or about how you play the sport?
- The class seemed to be controlled by the teacher. It was thought that this probably frustrated students, so they were asked about their feelings and whether or not they wished they could have more control.
- Memorization of how to do problems instead of understanding the reasoning behind solutions appeared from classroom observations to be an issue. Therefore, students were asked about how they went about learning how to solve problems.
- Students were asked if they became frustrated when taking the VOSTS because it appeared from observation that they were frustrated with its length.
- Individual inconsistencies in responses to the questionnaires were explored.

Phase 5

A member check was conducted with the students selected in Phase 4 and the teachers through scripted interviews. The interviews were audiotaped and took about 30 minutes each.

Most of the students were articulate and thoughtful in their responses. The interviews were the first indication that world view would be an important factor in conceptual change among these students, that the high conceptual change students had a remarkably complex and consistent understanding of physics concepts about the nature of forces, that low conceptual change students tended to work with low conceptual change students, and that high conceptual change students seemed to work alone or with other high conceptual change students. The interviews also confirmed that the students, even the low conceptual change students, were highly motivated, that many students were not making connections between everyday experiences and physics content,

that students did become frustrated with the length of the VOSTS, and that student responses on the questionnaires were being correctly interpreted. It was discovered, however, that they were counting out of class discussions with other students and interactions with neighboring students during lecture when they responded to opportunities for student negotiations items. The interviews were extremely useful because it was difficult to determine what students were thinking and feeling due to the low level of teacher-student and student-student interactions in this class.

Phase 6

Final analysis of the data was accomplished by triangulation of all data sources and relevant literature. This process took five months due to the complexity of the data sources. Assertions were developed that were supported by at least three pieces of evidence from the data sources. Additional findings were also listed. Then assertions and findings were put together to make conclusions about each separate classroom. During this process some additional data were taken from videotapes and audiotapes, the Force Concept Inventory was interpreted from another perspective, additional analyses were done on the questionnaires, and findings were discussed with the peer debriefed and with the study advisor.

World view had emerged as a factor in this classroom during student interviews. Therefore interviews were listen to again and the VOSTS was re-examined in an attempt to document the world view of particular students. Then, Mrs. Hamilton's responses on the VOSTS were compared to the responses of high and low conceptual change groups. A two-tailed Pearson Chi-square test was done to determine if the proportion of students agreeing with the teacher's responses was statistically significantly different ($p < .05$) for the high and low conceptual change students.

During interviews with high conceptual change students, they appeared to have a complex and consistent understanding of physics concepts about the nature of forces. Their responses on the FCI were examined for further evidence of this consistent understanding. The concepts required for a student to correctly answer each item on the FCI was determined. Then, the items that were answered incorrectly were analyzed to see if they had concepts in common and to see if there were any logical inconsistencies in responses.

Phase 7

A final member check was conducted with each teacher. The assertions and the supporting evidence were presented. The teachers also read the classroom's thick description, commented on its accuracy, and looked at a representative three-day videotape analysis of their teaching style. Teachers had the opportunity to correct any inaccuracies and to comment on the assertions and videotape analysis of their teaching styles.

Results

Analysis of Videotaped Teaching

The videotapes for both the physics teacher and the math teacher were analyzed using the Secondary Teacher Analysis Matrix (Gallagher & Parker, 1995). The designers of this matrix recommend videotape analysis of three days of instruction in order to classify a teacher's teaching style (K. Ham, personal communication, June 10, 1996), and indeed it appeared that any three-day analysis was about the same as any other. The videotaping began the 4th week of school and continued through the 10th week of school.

Mrs. Hamilton's Three-Day Analysis. Figure 1 shows the percentage of activities in each STAM scale (content, teacher's actions, students' actions, resources, and environment) that were evaluated as didactic, transition, conceptual, early constructivist, experienced constructivist, or inquiry during a three-day period. Mrs. Hamilton's teaching style was evaluated conceptual the majority of the time for content (65%), teacher's actions (72%), students' actions (77%), and resources (71%). However, the environment scale was evaluated 19% didactic, 44% transition, and 31% conceptual, and 6% early constructivist. Mrs. Hamilton displayed early constructivist

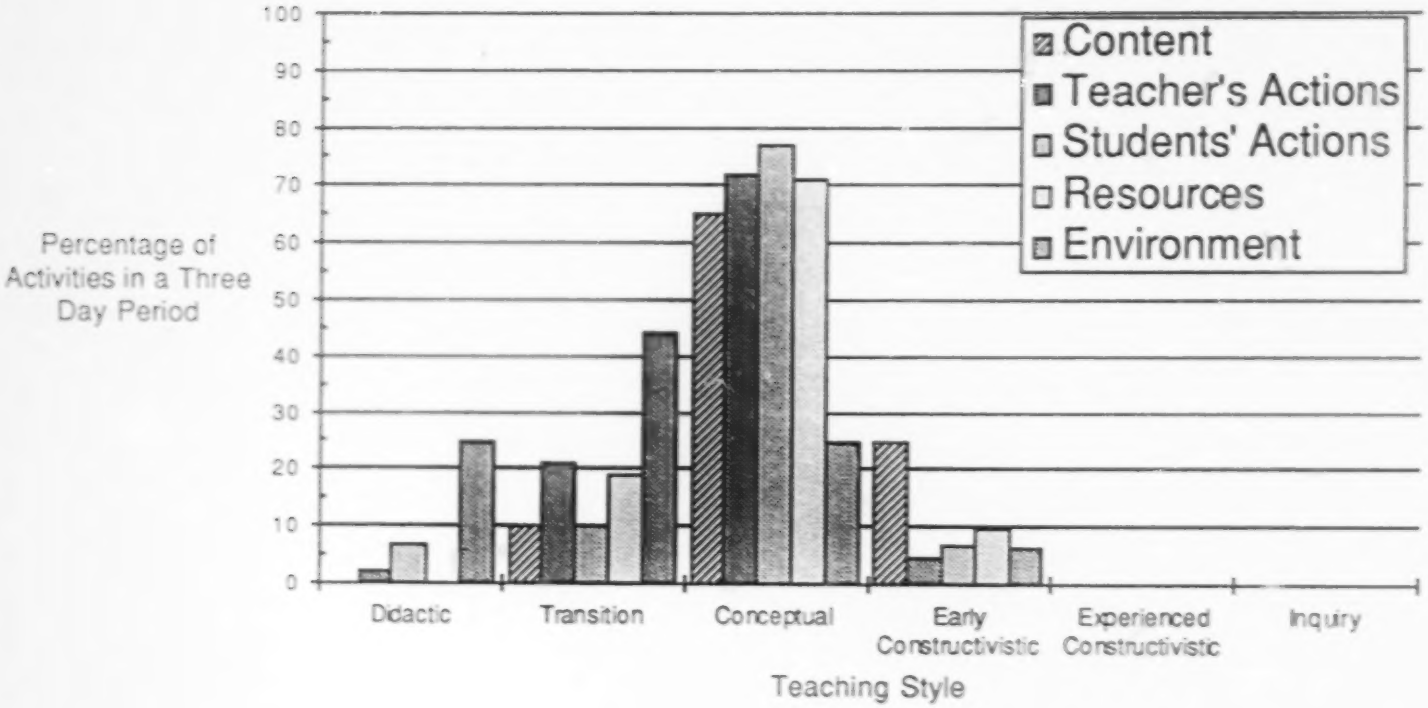

Figure 1. Physics Teacher Videotape Analysis of Instruction Using the Secondary Teacher Analysis Matrix (STAM)

aspects only during the lab and computer games in this three-day analysis. Mrs. Hamilton's teaching style was evaluated as primarily conceptual.

A conceptual teacher explains the structure of the content, makes examples and connections within the content, describes limits, exceptions, and multiple interpretations, and integrates the processes and the history of science into content. Mrs. Hamilton displayed these characteristics in 65% of the activities over a typical three-day interval. Mrs. Hamilton did an excellent job of explaining content and showing the interconnections among concepts.

A conceptual teacher uses many teacher-centered activities. Labs are conceptually focused; teacher-student interactions are about conceptual content; the teacher's questions are focused on concepts and connections; the teacher conducts both formative and summative assessments; the teacher responds to student ideas about content by trying to change ideas that are unscientific. Mrs. Hamilton displayed these characteristics in 67% of the activities during the three-day analysis. Her instruction was primarily teacher-centered.

In a conceptual classroom, students write and use other representations of ideas which are provided by the teacher; the students' questions are procedural and conceptual, student-student interactions are concerned with correctness of their ideas; student initiated activities consist of volunteering examples; and the students accept the teacher's expectations. The students in Mrs. Hamilton's class displayed these characteristics in 77% of the activities during the three day analysis.

In a conceptual classroom, there are multiple resources which are related to concepts. These resources are teacher controlled with some classroom discussion. Seventy-one percent of the activities in Mrs. Hamilton's class displayed resources with these characteristics.

In a conceptual classroom, decisions are teacher controlled except for some discussion of time usage; the teaching aids are varied and related to content; and there are many similar examples of student work. Mrs. Hamilton's classroom exhibited these environmental characteristics in 31% of the activities during the three-day analysis. Forty-four percent of the activities were evaluated as transition because teacher decision making failed to include even a discussion of time usage with students and there were only a small number of resources.

Classroom observation confirmed that Mrs. Hamilton is primarily a conceptual teacher. Her presentation of content followed a logical order that built upon previous content. She explained the connections among concepts and sought o change the unscientific views of her students. There were few attempts to determine the thinking of students or incorporate student ideas into discussions. Labs followed the presentation of content and confirmed or applied what had been taught.

The Constructivist Learning Environment Survey. The survey is divided into 5 scales: Personal Relevance, Uncertainty, Critical Voice, Shared Control, and Student Negotiation. The results of the CLES indicate that the classroom had few elements that are constructivist and that responses are consistent with a conceptual, or traditional environment.

The Personal Relevance scale measures whether students perceive that the teacher uses the context of everyday student experiences to teach scientific knowledge (Taylor, Dawson, & Fraser, 1995). The use of everyday experiences as a meaningful context for teaching provides opportunities for students to relate prior knowledge and experiences to new learning. Therefore, Personal Relevance should be an indicator of a constructivist classroom environment. The mean for Personal Relevance was 19.9. and corresponds to a mean response of 3.3 (or a little more than sometimes).

The Uncertainty scale measures whether students perceive that the teacher provides opportunities "to experience scientific knowledge as arising from theory-dependent inquiry, involving human experiences and values, evolving and non-foundational, and culturally and socially determined." (Taylor, Dawson, & Fraser, 1995, p. 5). This scale addresses some of the epistemological underpinnings of constructivism. As discussed in the review of the literature, many constructivists view science as value laden, thus it results in viable knowledge, not necessarily knowledge about reality. This scale reflects that viewpoint and also the less controversial viewpoint that scientific knowledge changes over time. The mean for this scale was 17.0. This corresponds to a mean response of 2.8 (a little less than sometimes).

The Critical Voice scale measures whether students think that it is acceptable and helpful for them to question the teacher's plans and methods and to express their concerns about factors that might be inhibiting their learning. (Taylor, Dawson, & Fraser, 1995). Participation in decision making is important for a constructivist classroom because it provides opportunities for students to help guide instruction. In this way, instruction can be more meaningful and more relevant to student needs and experiences. The mean for this scale was 20.6 which corresponds to a mean response of 3.4 (almost half way between sometimes and often).

The Shared Control scale measures the extent to which students feel that they share control of the learning environment with the teacher. Sharing the learning environment means that students can express their own learning goals, help design and manage their learning activities, and determine and apply their own assessment criteria. Student evaluation of their own conceptual development is important in a constructivist classroom. This scale attempts to assess this aspect of the learning environment (Taylor, Dawson, & Fraser, 1995). The mean for this scale was 10.9 which corresponds to a mean response of 1.8 (a little less than seldom).

The Student Negotiation scale measures the extent to which students feel that they explain and justify their ideas to other students and listen to and evaluate the ideas of other students. The purpose of this process is to get students to reflect critically on their own ideas (Taylor, Dawson, & Fraser, 1995). The reflection upon the viability of ideas is essential from a constructivist viewpoint because it is during this reflection that students incorporate new concepts or change their existing concepts. The mean for this scale was 24.1 which corresponds to 4.0 (often). This scale is the only one of the five scales that indicates a constructivist environment. It will be discussed in more detail later.

From these results, it appears that this learning environment has few constructivist characteristics with the possible exception of opportunities for students to discuss ideas with other students. This overall assessment agrees with classroom observations and the videotape analysis which characterizes the teacher as conceptual, or traditional in her approach to teaching physics.

Force Concept Inventory Pretest and Posttest

The Force Concept Inventory (FCI) was given the first-week of school. The posttest was given after instruction on forces was complete, during the 10th week of school. The highest possible score on the FCI is 30.

Pretest. The mean on the pretest was 7.8 with a standard deviation of 2.7. The highest score was 15 on the pretest. A score of 18 is considered the threshold for Newtonian thinking by the creators of the test (Hestenes et al., 1992). Therefore, none of the students in the study had reached Newtonian thinking before instruction according to this test.

Posttest. The mean on the posttest was 16.2 with a standard deviation of 6.1. The mean is still below the Newtonian threshold. A paired two-tailed t-test showed that the posttest mean was statistically significantly higher than the pretest mean. The analysis yielded a $t = 8.64$ which was statistically significant ($p < .0001$). (This corresponds to a normalized gain score, as defined by Hake (1996), of 0.38. This score indicates a medium amount of conceptual change when compared to Hake's scale.)

Delta Scores. Since the purpose of the study was to investigate conceptual change, it was necessary to calculate the change in scores from pretest to posttest. The change in score was called a delta score and was calculated by taking each student's posttest score and subtracting his or her pretest score. The minimum delta score, (or posttest - pretest) was -1 (meaning that one student did worse on the posttest) and the maximum delta score was 21. Eight of the 26 students in the study (31%) had posttest scores of 18 or better, which indicates that these students have reached the Newtonian threshold.

Research Questions and Analyses

Research Question 1: How do student views on the nature of science relate to conceptual change within a traditional high school physics classroom?

The primary data sources for this research question include context notes, videotape, videotape analysis, data about students in the class from the Views on Science-Technology-Society

(VOSTS) questionnaire, data about high and low conceptual change students (as identified by the Force Concept Inventory), and interviews of the high and low conceptual change students. However, the Personal Relevance and Uncertainty scales of the Constructivist Learning Environment Survey also relate to this question.

Assertion 1: Few of the students believed that science offers solutions to practical problems.

Items 40421 and 40431 of the VOSTS concern whether science is useful in solving everyday problems. For item 40421 ("In your everyday life, knowledge of science and technology helps you personally solve practical problems (for example, getting a car out of a snowdrift, cooking, or caring for a pet)."), approximately 81% of the responses indicated that students do not feel that science helps them solve everyday problems, and only 15% of the students chose responses that indicated that they believe that science does help them solve everyday problems. In response to item 40431 ("Scientists can solve any practical everyday problem best (for example, getting a car out of a ditch, cooking, or caring for a pet) because scientists know more science."), 58% of the students responded D ("Scientists are no better than others because in everyday life scientists are like everyone else. Experience and common sense will solve everyday practical problems."). Only 15% of the students agreed that scientists are better at solving practical problems (response A).

This assertion is further supported by interviews of both high and low conceptual change students. Students from both groups said that they do not think about physics when playing sports or when thinking about playing sports. A few students said that they think about physics occasionally while driving. For instance, one student said she thought about inertia when she turned her car and saw an ornament hanging from her rear view mirror swing away from the turn. However, most of them do not use physics to make decisions such as to slow down on wet pavement because the coefficient of friction is less on wet pavement than it is on dry pavement.

In addition, on item 2 from the CLES ("My new learning starts with problems outside of school."), only 23% of the students in the class responded almost always or often. Therefore, less than one-quarter of the students perceive that their current science course concerns itself with everyday problems.

Class observations confirmed that everyday applications were not a focus. Practical applications were sometimes presented in which students made calculations or measurements, but these calculations were rarely used to solve an everyday problem.

According to the conceptual change model of Posner, Strike, Hewson, and Gertzog (1982, p. 214), there are four conditions required for conceptual change to occur by accommodation: (1)"There must be dissatisfaction with existing conceptions;" (2)"A new conception must be intelligible;" (3)"A new conception must appear initially plausible;" and (4)"A new concept should suggest the possibility of a fruitful research program."

The fourth condition seems to be problematic for these students in the domain of every day experience. Posner et al. mean by "fruitful research program" that the new concept must appear to be useful. However, students did not seem to think that science is useful in solving everyday problems. This may have inhibited the conceptual change of some students. Moreover, why should they experience dissatisfaction with their current conceptions if they do not see an alternative way to solve everyday problems? There was an indication here that students were keeping their practical, out of school life separate from their in school learning.

Assertion 2: Student views on the nature of science seemed to be related to the amount of student conceptual change.

During the student interviews, 2 of the 6 low conceptual change students appeared to have characteristics of what Cobern calls an alternative or curved world view, and 2 of the 6 high conceptual change students appeared to have characteristics of an angular world view (Cobern, 1993). Individuals with an angular world view see those things outside of themselves as materialistic, reductionist and exploitive, use a natural classification system, see causality as mechanistic and telenomic, view relationships as objective and nonpersonal, see themselves as dispassionate, independent and logical; and view time and space as abstract formulations.

A high conceptual change student who will be called Josh seemed to have angular views. Josh had the largest delta score (21) in the class. During his interview, he said that he thought of himself as analytical and worked problems in a step-by-step logical manner. He liked to learn by working example problems from the book and trying to understand the reasoning behind each step. In his interview he stated,

> I see every time there's an example as a new problem and I tell myself, "I don't know this." So by doing this, I'll be able to make the connection and see what this person is thinking. And that way I will be able to apply this formula, this method to other problems....I write down the problem just so I don't miss any little parts. Then I write down all the givens and all the basic equations like they do in the book and usually after that, once I see the givens and the equations I click it in....A lot of times, to be sure, I go through and copy the solution too, but it's not just a matter of copying. You have to understand it.

His description of learning by working example problems from the book, illustrated his reliance on reasoning and logic and his ability to reduce seemingly different problems to their essential elements so that underlying similarities can be revealed. These are characteristics of an angular world view. In addition, Josh described himself as analytical.

The other high conceptual change student who appeared to have an angular world view will be called William. William scored a 15 on the pretest which was the highest pretest score in the class. When he was asked about how he did so well, he said that he used his knowledge of everyday occurrences to answer the questions. He could see the similarity between the FCI items and everyday occurrences. This required him to be able to reduce the situations down to relevant elements and isolate those elements so that he could see that the situations were really similar even though they had different contexts. In addition he described physics as being "pretty logical" and answered, "It was just logic." when he was asked how he solved a particular aspect of a projectile problem. William appears to rely on logic and to be able to reduce seemingly different problems to their essential elements so that underlying similarities can be revealed. These are both characteristics of an angular world view.

Individuals who have alternative views, or a curved world view, see those things outside of themselves as holistic, social/humanistic, aesthetic or religious, use classification systems that are natural, social, or supernatural, see causality as mystical, teleological, or contextual, view relationships as subjective and personal, see themselves as passionate, dependent and intuitive, and view time and space as tangible, participatory medium.

There were two low conceptual change students who appeared from their interview to have curved world view characteristics. Jill described herself as follows, "I'm not very analytical. Maybe that is why I don't do well in physics. I kind of feel the answer." When she was asked if "feel the answer" meant that she had intuition, she said enthusiastically, "Yes , that's it." She also reported that she sometimes had flashes of insight and that she found it difficult to understand Mrs. Hamilton's explanation of how to work problems. (Mrs. Hamilton used a linear step-by step approach to problem solving.) "Usually I write down what she says and then understand it later when I am on my own. For some reason I can't get it in class."

Tom, another low conceptual change student who appeared to have characteristics of a curved world view, was interested in the arts. In class, he felt that the emphasis was on solving problems by using formulas and that the material was not related to the real world. This bothered him a lot. He did not find it satisfying to be able to get the right answer unless he understood its relationship to reality also. Tom reported that he enjoyed the course only half the time. When he was asked why, he replied,

> ...sometimes the course, like drags on and seems like it's only formulas and well for me it doesn't seem that it relates the formula to actual life. I mean to what actually happens. It seems that there are these two separate areas. So when you work formulas you just do it mathematically, and you don't relate it to anything that actually happens. And maybe sometimes it does like when we do labs and stuff, but I, it still seems like there is not enough relationship between the actual things and formulas.

When he was asked why he had reported that he felt confident only once in a while, he said,

> Confident? I guess it's because, umm, sometimes I understand what I'm doing and so I feel confident. And like, and those are only the times when I know how to do the problem and also I know how to relate it to the real world and so I understand it completely, what it's talking about.

Tom's desire for wholeness here seems to be a curved world view characteristic. He is not satisfied with understanding the part. He needs to see the whole.

These observations and the analysis of the differences between high conceptual change students' and low conceptual change students' responses on the VOSTS and the Uncertainty scale on the CLES led to the following assertion:

A careful comparison of the physics teacher's responses on the VOSTS and the responses of both high and low conceptual change students and the class as a whole brought further evidence that views about the nature of science may be related to conceptual change within this environment. On the VOSTS questionnaire, the students in the class had the same response as the teacher on 24% of the items. High conceptual change students gave the same response as the teacher on 33% of the items and low conceptual change students gave the same response as the teacher on 16% of the items.

In addition, a two-tailed Pearson Chi-square test was done to determine if the proportion of students agreeing with the teacher responses was statistically significantly different for the high and low conceptual change students. The proportions for the two groups was shown to be statistically significantly different. (Pearson Chi-square = 16.56, df = 1, and $p < .00005$).

The VOSTS was not given as a pretest. Therefore it is possible to argue that the high conceptual change students learned the teacher world view. However, Cobern argues that world view is a deeper structure than conceptual change and therefore much more difficult to change. It is more likely that the students who entered the class with a world view that was similar to the teacher's would have had an advantage over students whose view of the world was different from the teacher's.

The classroom context appeared to favor those students who had an angular view of the world. This was probably due in part to the content itself. Classical physics depends on logic, reduction of the physical world to a set of abstract variables, causality, objective observations, and reasoning. However, the videotape analysis using the STAM also indicated that the content was presented in a logical, self-contained manner that did not incorporate student ideas or everyday experiences. The classroom itself appeared to be consistent with an angular world view. In addition, access to the content through intuition, personal experience, and holistic understanding were not addressed.

The Uncertainty scale on the CLES provided further evidence that the low conceptual change students have not only a different view of the nature of science, but that their view is indeed an alternative or curved world view. Figure 12 shows the number of responses for the items in this scale. The low conceptual students had higher means for 4 of the 6 items in this scale. The largest differences between means occurred on items 9 and 12.

On item 9 ("I learn that science is influenced by people's values and opinions."), the mean response for low conceptual change students was 3.5, which is half way between sometimes and often. The mean response for the high conceptual change group was 2.2, which is barely above seldom. The low conceptual change students seem to see science as more subjective and value laden than the high conceptual change group. This indicates that the low conceptual change students may have a more curved world view than the high conceptual change students.

In addition, on item 12 ("I learn that science is about inventing theories."), the mean response was 3.7 for the low conceptual change students, which is a little over half way between sometimes and often. The high conceptual change group had a mean response of 2.0 which is seldom. The perception that theories are inventions and not a consequence of observation and experimentation may indicate a subjective, personal view of the world. This indicates that low conceptual change students may have a more curved world view than high conceptual change students.

There was one remaining item from this scale that might indicate a curved world view. On Item 10 ("I learn about the different sciences used by people in other cultures."), the high

conceptual change students had a slightly higher mean (1.8) than the low conceptual change students (1.3), but those means are close and are both low (between seldom and sometimes).

Research Question 2: How do student attitudes about the classroom environment relate to conceptual change within a traditional high school physics classroom?

The primary data sources for this research question include context notes, videotape, videotape analysis, data about the students in the class from the Questionnaire for the Assessment of a Science Course (QUASC), data about high and low conceptual change students (as identified by the Force Concept Inventory) from the QUASC, and interviews of the high and low conceptual change students. However, the Personal Relevance scale of the Constructivist Learning Environment, which is discussed more fully under the section concerning the research question about environmental factors, also relates to this question.

Assertion 3: Few of the students seemed to believe that the content was useful to them and that it had to do with their everyday experience.

According to responses to responses on the QUASC, over one-half of the students felt that the information that is taught in the course is infrequently useful to them in a personal way. However, in spite these responses, 70% of the students responded most of the time or all of the time to item 7 ("The information should be required in science class."). Apparently, the students thought that information should be taught even if it is not personally meaningful to them. In other words, students did not expect school learning to be useful to them personally.

The Personal Relevance scale of the Constructivist Learning Environment (CLES) also supports this assertion. The Personal Relevance scale measures whether students perceive that the teacher uses the context of everyday student experiences to teach scientific knowledge (Taylor, Dawson, & Fraser, 1995). On item 1 ("I learn about the world outside of school.") only 32% responded almost always or often. However, only 23% responded almost always or often to item 2 ("My new learning starts with problems about the world outside of school."), and only 31% responded almost always or often to item 3 ("I learn about how science can be a part of my life outside of school.").

Classroom observation confirmed that while Mrs. Hamilton sometimes referred to how physics is all around us, specific applications of physics were for the most part problems from the book. These problems did not encourage students to access their prior experiences, because the information was presented in a straight forward, unambiguous manner. In addition, as the problems were solved in class, there was little attempt to use student experiences as a resource. The problems were solved in a formal manner. Draw a picture of the situation; write down what you know; write down what you want to find out; choose the appropriate equation; substitute what you know into the equation; and solve for the unknown.

From a constructivist framework, relating new learning to prior knowledge has been recognized as an important part of the learning process. Tobin and Tippens (1993) who advise using the concept of constructivism as a referent for instructional decisions, advocate that the learner should be the focus of instruction, not the discipline. Knowledge is individually constructed by the learner within a social context and therefore requires that learners make sense of new learning through existing knowledge structures. This process involves reconciling new knowledge with prior knowledge and experiences. It appeared that while new knowledge is reconciled with other physics content, students were not encouraged to reconcile it with their own personal experiences or constructs. In addition, the reconciliation of new content with prior content was done primarily by the teacher.

Von Glasersfeld (1993) lists several implications of constructivism for instruction. One of the implications is that a teacher needs to understand the concepts and conceptual models of students if they wish to change them. There was not much evidence of an attempt to bridge or access student prior constructs or experiences. The emphasis was on constructing meaning within the content of physics itself. In other words, it is possible to define acceleration from the concepts of velocity and time interval and to construct F = ma from the concepts of mass and acceleration. There seemed to be few attempts to assess what students already know about motion or forces

from their own personal experiences and reconcile those experiences with the more formal, abstract concepts of velocity, acceleration, and force within the discipline of physics. More importantly, students themselves were not engaged in the process according to the QUASC, CLES, and student interviews. According to Posner et al. (1982) conceptual change requires a dissatisfaction with existing conceptions. There can be no dissatisfaction if students do not believe that the new concepts have anything to do with everyday experiences because they will not try to apply the new concepts to their prior experiences. They will only apply them within the physics content itself. Furthermore, it seems that concepts taught in isolation from everyday experiences can only be intelligible to students in a limited way within the physics content. Students will probably not make an attempt to understand them in a more personal way and reconcile the formal concepts with their personal experiences. In addition, their personal experiences are not able to help them understand the formal concepts or to apply them, either in lab or solving problems.

On the other hand, learning physics concepts within an isolated system presupposes that the concepts are plausible and fruitful within the physics content. Students in this environment should not suffer the conflict that students usually experience when trying to make sense of physics concepts within everyday contexts. There may be less confrontation as a result of keeping the physics concepts separate from everyday experiences; and certainly the students would see the concepts as fruitful because they could use them to solve written problems. Although the conflict necessary for restructuring of existing constructs is not present, students may be able to construct new isolated constructs without having to work through cognitive conflicts that can be difficult for students.

This view is further substantiated by Osborne and Wittrock (1983). Their model for conceptual change is the generative learning model. According to Osborne and Wittrock, instruction is often ineffective in changing the constructions students bring with them to the learning environment because learners sometimes make only minimal links between newly constructed meanings and long term memory. By making only minimal linkages students are able to construct "isolated knowledge structures" which they use only within the science classroom (Osborne & Wittrock, 1983, p. 500).

In view of these findings and these theoretical frameworks, how is it then that some the students in this class were able to experience a great deal of conceptual change? The gains of the class as a whole were moderate, but some individual had large gains. Analysis of the findings have led to the following assertion:

Assertion 4: High conceptual change students seemed to be able to either make their own connections between the content and everyday experiences or to construct the concepts as "isolated knowledge".

The evidence for this assertion comes primarily from the QUASC, classroom observations, and student interviews. A comparison of the responses of high and low conceptual change students to the "How Useful Is the Information?" category on the QUASC reveals that high conceptual change students have slightly higher means for each of the items in this category. The largest difference in means was on item 8 ("I will be able to use this information in the future." The mean score for high conceptual change students was 3.0 (sometimes), and the mean score for low conceptual change students was 2.2 (slightly more than once in a while). However, none of the means were higher than sometimes with the exception of item 7 ("The information should be required in science courses."). However, a closer examination of the high conceptual change students' responses revealed that 3 of the 6 high conceptual change students found the information to be frequently useful. The assertion was further supported by classroom observation and student interviews.

Susan, a high conceptual change student, asked questions in class that illustrated that Susan was attempting to relate physics concepts to her prior experiences and everyday situations. She wanted the concepts to make sense.

During the unit on projectile motion, Mrs. Hamilton, in response to a student question stated that if one bullet was dropped and another bullet was shot horizontally from a rifle at the same moment that both bullets would hit the ground at the same time. Mrs. Hamilton said that they

should hit the ground at the same time and that the only force acting on both bullets was the force of gravity. The following discussion then took place:

Susan: But, isn't there a force that propels it forward?
Mrs. Hamilton: What. Oh! Shades of Aristotle. What force propels the bullet forward from the gun the instant it leaves the barrel?
Student: Air.
Mrs. Hamilton: Ooo. Wait a minute. Huh? What force propels the bullet horizontally the instant that it leaves the barrel?
Students: [garbled.]
Mrs. Hamilton: Not a force.
Students : Nothing. Nothing.
Mrs. Hamilton: Nothing! Thank you.
Susan: But there has must be some kind of force or else it will just stop because if there's nothing on the other side of it...[garbled.]
Mrs. Hamilton: That is a typical misconception and that's ok. That's all right.

Then, Mrs. Hamilton used an example of a ball rolling on a table and ask what kept the ball rolling after she quit pushing it. Several other misconceptions emerged from other students. Students suggested it was the table or gravity that made it continue to roll. One student said that it was the "force of acceleration" which implied a confusion of the concepts of acceleration and force. Mrs. Hamilton then brought up the concepts of impetus and inertia and reminded students of Newton's first law of motion.

Mrs. Hamilton: Newton's first law says that if there's no net force on it then the velocity's constant. Do you agree with that ? Do you have a problem with that?....It keeps on rolling because it has inertia. Agree with that? It's inertia wants it to keep going.

Susan seemed unsatisfied even after Mrs. Hamilton showed a video of a dropped ball and a horizontally launched ball (Physics Cinema Classics, 1990) that showed the two balls hitting the ground at the same time. Mrs. Hamilton, as a strong conceptual teacher, did a fine job of relating concepts within the discipline and demonstrating that they were internally consistent, but Susan was trying to make sense of the concepts in terms of her own experience.

William received the highest score in the class on the pretest. When I asked him how he was so successful, he said that he had noticed how forces act. For instance, he had noticed how balls move in the air when thrown or dropped. When asked about item 21 on the FCI (concerning the motion of a rocket when force is applied while it is traveling at constant speed), which he answered correctly, he said that he had played a computer game at home in which he had to apply a force to get a rocket to move in a particular direction. He thought of the game during the pretest and remembered that if the rocket was moving horizontally at a constant speed that pushing vertically makes the rocket move in an arc. William not only seemed observant, but also able to reduce situations to a set of relevant elements. He scored 29 out of 30 on the posttest.

Only three of the high conceptual change students responded positively about applying physics to sports, driving, or other everyday activities. During his interview David stated, "I just don't think about these things very much outside of class. Like most of the time I'm thinking about what is outside of class in class, but I don't think about what's in class outside of class." Another high conceptual change student, who will be called Ben, said, "I don't think it is meaningful or useful," when he was asked about the usefulness of the information in the course.

The interviews seemed to indicate that high conceptual change students were either relating what they learned to everyday experience to make sense of the concepts or constructing physics concepts in a system that was isolated from everyday experiences. It appears that the students were split evenly.

What about the low conceptual change students? They answered less positively on this section of the QUASC and seemed less able to construct the knowledge in isolation. It is unclear why they were less able. They certainly seemed to be just as motivated. However, classroom observations and student interviews seem to indicate that many of them were putting their efforts into memorizing how to do problems. They thought that they were supposed to do that. Cobern

says that students who have a curved world view try to cope with angular science instruction by memorizing. However, the memorizing might also have been a method of coping with formal reasoning difficulties. The study did not measure the formal reasoning of students. Therefore, this analysis is beyond the scope of the study.

Research Question 3: What classroom environmental factors seem to facilitate conceptual change within a traditional high school physics classroom?

The primary data sources for this research question include context notes, videotape, videotape analysis, data about students in the class from the Constructivist Learning Environment Survey (CLES), data about high and low conceptual change students (as identified by the Force Concept Inventory) from the CLES, and interviews of high and low conceptual change students. The assertions will be supported by at least three of these data sources.

One of the advantages of a conceptual environment is that content can be presented in a very logical and internally consistent manner. Student ideas and everyday experiences do not interrupt the flow of the presentation of the material. Although content should be internally consistent in a constructivist classroom, sometimes the interconnections between concepts are not as clear because they are developed over a longer period of time and are intertwined with student ideas that must be reconciled with the content. Students who have an angular world view and who have developed the required formal reasoning ability may be able to make large gains in conceptual understanding. However, within this classroom, as was discussed previously, the knowledge may be isolated from their everyday experiences and prior knowledge.

Assertion 5: Presenting the content in a logical manner enabled most of the high conceptual change students to develop an internally consistent understanding of the content.

A careful analysis of the items missed by high conceptual change students reveals that 5 out of 6 of them seem to have developed an internally consistent understanding of the content. The highest scoring student, who will be called William, answered 29 out of 30 items (missed item 15) Item 15 is a difficult question involving Newton's third law in an accelerating system. Josh answered 28 out of 30 items correctly (missed items 15 and 26) . Item 26 involves Newton's first and second laws, and is complicated by the fact that 2 forces are acting in opposition to each other. The high scores of these students indicate that they have an internally consistent understanding of the concepts. However, analyzing the questions missed by these students was not very useful in determining the nature of their constructs because they missed so few questions.

The other four students had scores of 26, 25, 23, and 22. The analysis of the items that they missed reveal an internally consistent understanding of the concepts for three of the students. order to respond. It should be recognized, however, that some of the items may be answered by intuition, experience, or memorization. If a student's knowledge is internally consistent, then most of the items that he or she missed should be related by a few misunderstood concepts; the student should not be able to answer other items that require those misunderstood concepts; and finally, the student should correctly answer only those items which are logically consistent with the misunderstood concepts.

Joe with a score of 26 missed items 4, 15, 28, and 29. Each of these items involved Newton's third law. There was only one item (16) that Joe was able to answer correctly that involved Newton's third law. Of the 26 items that Joe answered correctly, none of them revealed a logical inconsistency with his misunderstanding Newton's third law. Therefore, it appears that Joe has an internally consistent understanding of the concepts evaluated by the FCI.

David had a score of 25 and missed items 4, 15, 17, 28, and 29. Four of the 5 items involved Newton's third law. There was only one item (16) that David answered correctly that involved Newton's third law. Notice that this is the same Newton's third law question that Joe answered correctly. David also missed item 17. The reason he missed this item is not readily explainable. Of the 25 items that David correctly answered, none of them revealed a logical inconsistency with his misunderstanding Newton's third law. Therefore, it appears that David has an internally consistent understanding of the concepts evaluated by the FCI.

Susan, who had a score of 23, missed items 15, 17, 19, 23, 25, 26, and 28. Five of the seven items that were missed seemed to involve two conceptual problems. Items 15 and 28 both involved applying Newton's third law to situations which involved acceleration. There were no items of this type that she answered correctly. However, Susan could apply Newton's third law correctly in situations where the objects were either continually at rest or moving at constant velocity (4, 16, and 29). She also had trouble with items that involved net force when more than one force was acting and the object was in motion (items 17, 25, and 26). There were no items of this type that Susan answered correctly. Two of the missed items are difficult to explain. In item 19 she missed a relatively easy question about the definition of velocity. It seems clear from the rest of her test that she understands that concept. She may have incorrectly interpreted the diagram. She also missed item 23 when she had answered similar questions correctly. However, 5 out of the 7 items that she missed can be explained by two conceptual misunderstandings. In addition, she missed all of the items in which she needed to apply those concepts and there were no logical inconsistencies between her misunderstood concepts and correctly answered items. Therefore, it appears that Susan has an internally consistent understanding of the concepts evaluated by the FCI.

Allen with a score of 22 is the only one of the high conceptual change students who appears to have logical inconsistencies between his correct answers and incorrect answers. Allen missed items 3, 5, 11, 13, 15, 18, 29, and 30. These missed questions involve 2 concepts. Five of the missed items (5, 11, 15, 18, and 30) involved a common misconception. Allen appears to believe that a force is required in the direction of motion for an object to move, even at constant velocity. However, he answered correctly items 24 and 23 which involve the idea that when no force is acting on an object, its velocity is zero and items 17 and 25 which involve the idea that when the net force on an object is zero, its velocity is constant. In addition, Allen was able to correctly answer items (21, 22, 26, and 27) which involve the idea that a non-zero net force results in an acceleration in the direction of the force. These correct responses indicate logical inconsistencies in his thinking

The remaining 3 items (3, 13, and 29) involve another common misconception. These items indicate that Allen believed that a constant downward pull of gravity is not enough to explain the motion of objects in free fall close to the surface of the earth and, a related misconception, that objects at rest on a level surface have more than the force of gravity and the normal force exerted by the surface acting on them. There were no items that he answered correctly that involved these ideas. However, he correctly answered items 12 and 14 which had to do with the trajectory of horizontally launched objects in free fall. The parabolic trajectories of objects in free fall are explained by a constant downward force of gravity. Allen may have simply memorized the shape of the trajectories and, therefore, never realized the inconsistency in his thinking. It appears that the items that Allen answered incorrectly reveal only two misunderstandings, but the items he answered correctly reveal many logical inconsistencies in his understanding of the concepts evaluated by the FCI.

In summary, this pattern seems to suggest that 5 out of the 6 high conceptual change students have a well developed, internally consistent understanding of many concepts. They did not understand a concept in only certain contexts and their correct responses did not reflect any logical inconsistencies with misunderstood concepts. This finding may reflect a well organized set of constructs in 5 out of 6 high conceptual change students.

One of the strengths of conceptual teaching is that the material is presented in a logical sequence that follows the structure of the discipline. Robert Gagne's hierarchical structure of learning (Hill, 1985) emphasizes the importance of task analyzing a complex skill so that prerequisite skills can be taught first. The idea is to teach prerequisite skills, and then to combine the pre-requisite skills already attained by the student so that they can accomplish more difficult tasks. Mrs. Hamilton's logical presentation of material followed this hierarchical form. This process does seem to have been successful with some highly motivated, high ability students. The question is why wasn't it successful with the low conceptual change students? It may be because, as discussed earlier, high conceptual change students tend to have a more angular world view than low conceptual change students and the material when it is presented in this logical manner makes more sense to students with an angular world view and the prerequisite formal reasoning skills.

Assertion 6: Student interactions (except for labs) were primarily self-selected. Low conceptual change students tended to work with low conceptual change students and high conceptual change students tended to work alone or with other high conceptual change students.

On the CLES Student Negotiation scale, approximately three-quarters or more of the students responded almost always or often to 4 out of the 6 items. Eighty percent of the students responded almost always or often to item 25 ("I get a chance to talk to other students."); 77% responded almost always or often to item 26 ("I talk with other students about how to solve problems."); 77% responded almost always or often to item 28 ("I ask other students to explain their ideas."); and 72% responded almost always or often to item 30 ("Other students explain their ideas to me.").

On the remaining two items, item 27 ("I explain my ideas to other students.") and item 29 ("Other students ask me to explain their ideas.") students responded almost always or often 62% of time and 54% of the time respectively. These responses still indicate that over half the class felt that student negotiation occurs frequently.

These results were somewhat surprising when compared to the analysis of the videotapes. Students seemed to think that more negotiation was going on than the video analysis indicated. Subsequent student interviews showed that students were counting communications after school, during lunch, between classes, and discrete communication with nearby students during lectures in addition to the time allocated during class by the teacher for student negotiation. This result suggests that both high conceptual change students and low conceptual change students were highly motivated and frequently worked outside of class on physics. In addition, when the students talked about who they worked with in groups, it became apparent that low conceptual change students tended to work with low conceptual change students and high conceptual change students either worked alone or worked with other high conceptual change students.

Lab groups were assigned. However, in class when there were opportunities to work in small groups, students were allowed to choose their own groups. Although there were some exceptions, the low conceptual change students tended to form groups with other low conceptual change students and the high conceptual change students tended to work alone or with other high conceptual change students. This grouping seemed to help the high conceptual change students because they were all engaged in understanding concepts and the relationship among the concepts. However, the groupings did not seem to favor students who were not high conceptual change students because groupings tended to reinforce the idea that the way to learn physics was to memorize how to work the problems.

Group work in science class is often advocated by science educators. Many of them cite Vygotsky's work as a theoretical basis for students working in groups. However, it is important to remember that Vygotsky's zone of proximal development (Vygotsky, 1978) requires a person who is more capable to help someone less capable. In the situation described above, everyone was at about the same level, and they all erroneously believed that their goal was to memorize how to work problems. There was no one in the group to provide scaffolding to help them improve their problem solving skills. It would seem that groups of mixed ability would be more beneficial to low performers than groups consisting of only low performers. In addition, the high performers would still benefit because providing the scaffolding for less capable students would help them refine their own understanding of the concepts.

Findings

The classroom was discipline-centered, and therefore was concerned with the development of concepts and the elucidation of their interconnections within physics. The course content remained within the discipline of physics itself, and rarely incorporated real world examples or student ideas. There was an emphasis on solving word/math problems, and there were few hands on activities. The students were highly motivated and high ability.

Within this conceptually oriented classroom, a comparison of high and low conceptual change students indicated that high conceptual change students (the six students with largest delta

scores) had beliefs about the nature of science that were more similar to the teacher's beliefs. Furthermore, high conceptual change students seemed to be more likely to have an angular, or logical world view. Classroom observations showed that the content was presented from an angular world view. In addition, many of the low conceptual change students (the six students with lowest delta scores) expressed frustration with their ability to understand teacher explanations which were usually logical arguments that stayed within the physics content. Therefore, it appears that student beliefs about the nature of science and a student's world view may be related to the amount of conceptual change that students experienced within this context.

Five of the high conceptual change students were able to develop an internally consistent understanding of the content. This development was probably facilitated by the logical presentation of the content (which made sense to them), and the teacher's emphasis on interconnections among the concepts. Three of the conceptual change students also reported that they related the physics concepts to everyday situations. However, the other three high conceptual change students appeared to have constructed their physics concepts in isolation, without reconciling everyday experiences.

Clearly, three of the five high conceptual change students attained a conceptual change that is of the highest caliber. Their knowledge structures are complex and internally consistent, and what is more they have attained some reconciliation between these new concepts and their everyday experiences. What about the rest of the class? Many students made important gains (Almost one-third of the students reached the threshold that indicates Newtonian thinking.). However, the surveys show that few of the students believed that the content was useful to them or had to do with their everyday experience. In addition, low conceptual change students expressed frustration with the course and showed only small conceptual gains in spite of the fact that most of them were in study groups or had tutors. All but one of the low conceptual change students appeared highly motivated, and yet the content seemed inaccessible to them.

In summary, highly motivated, high ability students, who were able to reduce complex situations to relevant elements and who found logical arguments satisfying, were able to excel in the conceptual environment. Many other students were able to make important gains. However, some highly motivated, high ability students found the content inaccessible, and few students in the class saw the content as useful outside of the physics classroom.

Reflections

Conceptual classrooms are efficient. Material is presented in a logical manner that emphasizes the interconnections among concepts. This presentation of material enables some of the most able and motivated students to experience a large amount of conceptual change. However, this conceptual change does not appear to be integrated into many of these students' existing knowledge structures. The gains appear to be isolated from the students' prior experiences and to be considered useless by them in the everyday world. Furthermore, the presentation of material in this manner seems to favor those students who have a logical, or angular world view and ignore the needs of students who have an intuitive, or curved world view (Cobern, 1993). As a result, some high ability, highly motivated students experience small gains. In addition, other important goals of science education seem to be left behind. Developing scientific ways of thinking requires opportunities to practice scientific ways of thinking. Similarly, students do not learn how to apply science concepts and ways of knowing without practice. However, if the course moves to more student-centered instruction that includes more hands on experiences and opportunities to apply ideas in real world situations and that accommodates individual students' ways of thinking, we may find that the amount of conceptual change will be smaller for the highest ability students with angular world views but, physics would make more sense to a larger number of students and additional educational goals would be met.

Implications for Further Research

In this study, world view seemed to be a factor in conceptual change. However, the analysis of world view had to be done in retrospect from listening to the interviews because it was through the interviews themselves that world view was first recognized as a possible factor. The

influence of world view needs to be documented more carefully in the more traditional classroom by assessment of the students' world views before instruction, by identification of possible sources of conflict during classroom instruction, and interviews with students to verify that these conflicts are occurring. It might be argued that physics itself possesses an inherently angular, or essentially logical, world view and that instruction must therefore also be angular in nature. More research needs to be done to explore how physics content can be made more accessible to students who are intuitive.

Many of the students in this traditional classroom seemed to have constructed physics concepts that are isolated, or loosely connected to their knowledge framework. Some might argue that this is not a problem. These students can make more connections to everyday experiences later. The important thing is to get the concepts into their knowledge framework. There are two problems with this argument. First, it is unlikely that they will make more connections unless they see the need for more connections. When will the need arise? It might arise in a college level course, but they seem unlikely to take physics unless it is required. The need will probably not occur in everyday life because most of them believe that physics is not useful and, therefore will not be expecting to apply it. Secondly and more importantly, these students may not remember the content long enough for the connections to occur because the content is not very well connected to experiences in long term memory. It would be very interesting to repeat the posttest after a year, but before further physics instruction to see if the gains are maintained and to see if the students from the constructivist class maintain their gains longer.

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Appendix : Assertions and a Summary of Evidence and Sources

Research Question 1: Concerning Student Views on the Nature of Science

Assertion 1: Few of the students believed that science offers solutions to practical problems.

Evidence	Source
• Less than one-fifth of the students thought that science helps them solve everyday problems.	VOSTS: Item 40421
• A little over one-quarter of the students thought that scientists are better at solving everyday problems than other people are.	VOSTS: Item 40431
• Less than one-quarter of the students perceived that their current science course concerned itself with everyday problems. This result was confirmed by classroom observation.	CLES: "Personal Relevance" scale and Classroom observation

Assertion 2: Student views on the nature of science seemed to be related to the amount of student conceptual change.

Evidence	Source
• Two low conceptual students exhibited characteristics of Cobern's curved world view, while two high conceptual change students exhibited characteristics of an angular world view.	Student Interviews
• The classroom was consistent with an essentially angular world view.	Videotape analysis
• High conceptual change students had views on the nature of science that were more similar to the views of the teacher than low conceptual change students.	VOSTS comparison with teacher's responses
• Low conceptual change students had a more curved world view of the nature of science than high conceptual change students.	CLES: "Uncertainty" scale (high and low conceptual change comparison)

Research Question 2: Concerning Student Attitudes

Assertion 3: Few of the students seemed to believe that the content was useful to them and that it had to do with their everyday experience.

Evidence	Source
• Over one-half of the students felt that the information taught was infrequently useful or meaningful to them personally, and about one-third of the students felt that they would be unable to use the information in the future. In spite of this however, almost three-quarters of them thought that the information should be included in the course.	QUASC: "How Useful Is the Information?"
• Only one-half of the students perceived that their learning frequently had some general connection to their life outside of school and only one-quarter to one third of the students perceived that their learning frequently had more specific connections to their life outside of school.	CLES: "Personal Relevance" scale
• For the most part, applications were problems from the book, and these problems did not encourage students to access their prior, everyday experiences.	Classroom observation

Assertion 4: High conceptual change students seemed to be able to either make their own connections between the content and everyday experiences or to construct the concepts as "isolated knowledge".

Evidence	Source
• Many high conceptual change students and low conceptual change students both thought that the learning was not useful to them and had little to do with their everyday experiences.	QUASC: "How Useful Was the Information?"
• Susan brought up a misconception involving projectiles during class discussion.	Classroom observation
• Three out of the six high conceptual change students reported that they did not think about physics in connection with sports or driving.	Student interviews
• Three out of the six high conceptual change students reported that they did not think about everyday experiences while solving physics problems.	Student interviews

Research Question 3: Concerning Classroom Environment

Assertion 5: Presenting the content in a logical manner, enabled high conceptual change students to develop an internally consistent understanding of the content.

Evidence	Source
• Material was presented in a very logical and internally consistent manner.	STAM analysis of videotapes
• Material was presented in a very logical and internally consistent manner.	Classroom observations
• High conceptual change students seemed to have a well developed, internally consistent understanding of many concepts.	FCI: Item analysis of questions missed by high conceptual change students
• Presentation of content in class followed the text presentation.	Classroom observations
• Some high conceptual change students reported learning most of the material before lecture and then being able to figure out from the lectures anything that they did not understand.	Student interviews of high conceptual change students.

Assertion 6: Student interactions (except for labs) were primarily self-selected. Low conceptual change students tended to work with low conceptual change students and high conceptual change students tended to work alone or with other high conceptual change students.

Evidence	Source
• Between one-half and over three-quarters of the students felt that they had frequent opportunities to discuss their ideas with other students.	CLES: Student Negotiation scale
• Students were counting communications after school, during lunch, between classes, and discrete communication with nearby students during lectures in addition to the time allocated during class by the teacher for student negotiation.	Student interviews
• Students were self-selecting groups for classroom activities accept for labs.	Classroom observations
• Low conceptual change students tended to work with low conceptual change students.	Student interviews and classroom observations
• High conceptual change students tended to work with high conceptual change students or by themselves.	Student interviews and classroom observations